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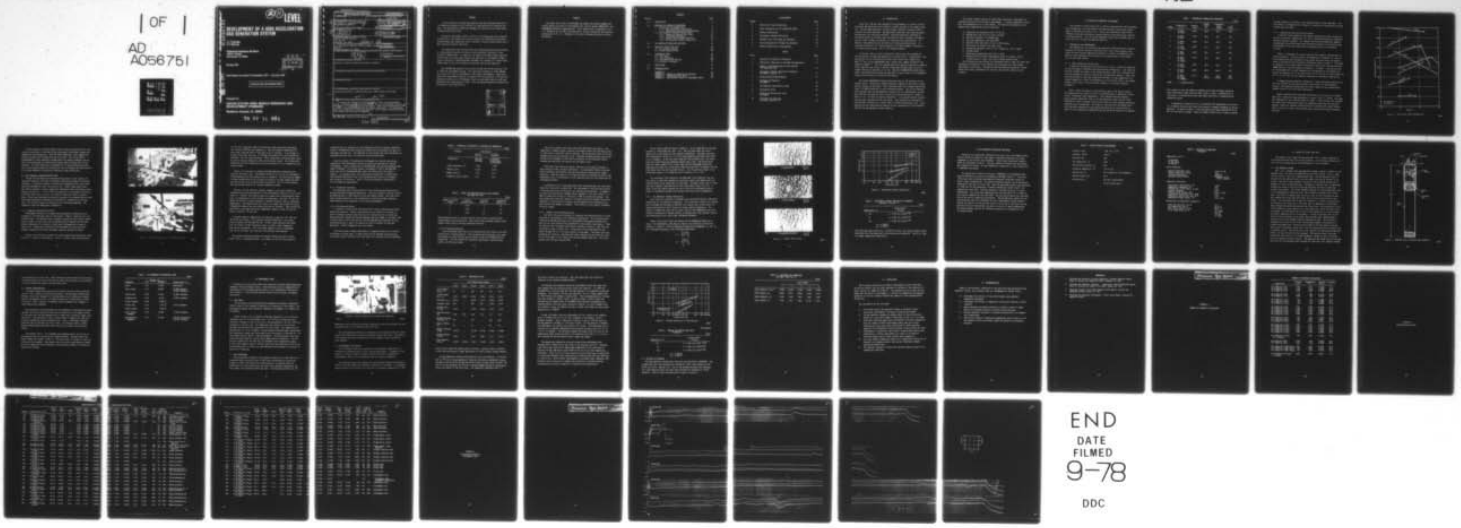

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DEVELOPMENT OF A HIGH ACCELERATION GAS GENERATION SYSTEM

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A program was conducted to develop further a solid fuel gas generator system. The gaseous output was cool (<550°F) most of its operating time and contained no large (>10 μm) particulate matter. Tests were conducted from -40° to 165°F to determine ignition delay and thermal sensitivity. Six conformance tests were conducted in flight-type hardware. Five complete nitrogen gas generator systems were delivered to MIRADCOM.

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SUMMARY

A solid propellant nitrogen gas generator has been developed which has a low temperature gaseous output suitable for supplying control actuation systems. The gas generator system was designed for operation after sustaining a 25,000-g acceleration load.

During the development effort a series of 19 formulations were evaluated theoretically, and prepared and tested to define the formulations providing a minimum exhaust gas temperature while retaining a suitably high burning rate to meet tentative envelope restraints.

Two formulations were selected from the screening evaluation and subjected to a processing evaluation to achieve a more consistent burning rate than previously demonstrated. In addition, the exhaust from these formulations was filtered and the filters were examined for particles in the exhaust by SEM. A single formulation of $NaN_3/Fe_2O_3/MnO$ (UTG-FM64) was selected for further development based on the very low particle expulsion from the gas generator.

The UTG-FM64 gas generator was carried through full-scale testing at -40° to 165°F and conformance testing. Six tests were conducted at three temperature levels for proof of conformance to the target requirements. These tests showed the requirements were met or exceeded with the exception of the gas temperature which was up to 190°F greater than the requirement when the test gas generators were conditioned at 165°F. Five nitrogen gas generator systems were delivered to the program office.

PREFACE

The author would like to acknowledge the support and helpful suggestions offered during the course of the program by Mr. Carl H. Warren (DRDMI-TGC), the USAMIRADCOM technical program monitor. Also, appreciation is expressed to Dr. J. D. Breazeale for his many contributions to several theoretical and practical problems and to Mr. R. L. Gramenz for his help in system fabrication and data acquisition.

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1.0 INTRODUCTION

Since 1971, CSD has been working on the development of a series of solid propellant gas generators which produce a single pure gas as the primary product. Typical gases generated include nitrogen, hydrogen, fluorine, carbon dioxide, and carbon monoxide. Gas generators producing other specialty gases and mixtures also have been developed. These gas generators represent an attractive method of storing a gas, particularly from a volumetric standpoint and also from a weight consideration in some particular applications. In general, these generators can provide the following characteristics: (1) long-term storability, (2) stable operation, (3) high volumetric efficiency, (4) reduced system weight, and (5) cost competitiveness.

In previous years, various contractual efforts have been conducted to develop specific nitrogen gas generators for certain uses. In particular, work was carried out for the Picatinny Arsenal under contract No. DAAA21-74-C-0506[1,2] and for the USAMIRADCOM under contract Nos. DAAH03-74-C0353[3] and DAAH01-75-C-0801[4]. The first program used three generator grains to produce a 10-sec starting flow of gas, a 260-sec sustaining nitrogen flow, and an on-command 300-psi gas delivery for 10 sec. The first USAMIRADCOM program developed a cartridge-loaded nitrogen gas generator to provide gas for the pneumatic flight control system of the Honest John missile.

The second USAMIRADCOM program referenced above is the precursor to the present effort. During this program the general design for the filter and gas delivery system was developed. Units developed under this program were tested under a 10,000-g acceleration load at Redstone Arsenal. The initial Redstone test performed with the gas generator oriented with the exposed grain surface away from the acceleration field, resulted in surface spalling to a depth of about 0.5 in., as shown by posttest inspection. A six-ported surface retainer disk was then incorporated into the design. This modification provided successful grain retention in a second test at 10,000-g acceleration load. Grain ignition was not significantly affected by the incorporation of the retention disk and the gas generator burned normally.

The present program retains the same target operational requirements as previously specified with two major improvements: a reduced temperature outlet gas, and demonstration of a clean exhaust. The desired requirements at all ambient grain temperatures are the following:

A. Operating time selectable from 4 to 30 sec
B. Minimum flow rate of 0.011 lb/sec nitrogen
C. Operation pressure of 1,000±100 psia
D. Exit gas temperature less than 550°F
E. Ignition delay less than 0.2 sec to 70% pressure
F. Particulate in exhaust less than 10 μm
G. Maximum gas generator size of 2-in. diameter by 13-in. length
H. Minimum weight
I. Operational temperature from -40° to 165°F
J. Operation after 25,000 g longitudinal shock of 10 msec, 2,500 g forward shock of 1 msec, and 2,500 g random lateral shock.

The following sections discuss the techniques used to lower the outlet gas temperature and produce a clean exhaust while retaining the other target requirements listed above. Discussion covering propellant selection, system design and stress, conformance test results, and delivery items also are included.

2.0 NITROGEN GAS GENERATOR DEVELOPMENT

The objective of this effort was to develop a gas generator which produces warm nitrogen gas (less than 550°F) while meeting other operational requirements of burning rate, density, etc. Theory and experimental results were combined during characterization testing leading to preliminary data required for design analysis. The following paragraphs discuss the processes used to select and test the warm nitrogen gas generator.

2.1 THEORETICAL GAS TEMPERATURES

Gas temperatures of prospective gas generator formulations were initially estimated by heat-of-reaction calculations and, later, using computer techniques for more refined temperature evaluation. Results of temperature estimates by both techniques are discussed as are implications of their operation in the flight system.

2.1.1 Heat-of-Reaction Calculations

A series of calculations was carried out to survey a variety of oxidizers for use with NaN_3 as candidate warm gas generator formulations. The flame temperature estimate was based on the energy released ($-\Delta H$) for a selected reaction and assumed all reaction products had the same heat capacity. These computations allowed a rapid and inexpensive estimate of flame temperature for a given composition. While the assumption is not entirely correct, the energy release values allow a fairly accurate ranking of the various candidate oxidizers.

Table 1 lists the results of calculations used in the initial survey; the formulations are listed in order of increasing heat of combustion (effectively, increasing flame temperature). This ranking shows the baseline Fe_2O_3 oxidized composition used in the gas generators tested earlier under acceleration loads in seventh place with at least six azide systems potentially yielding cooler nitrogen gas. Of these six, two have been considered previously and were rejected; the ZrO_2 system was found to be very difficult to ignite and the Fe_2O_3/Al_2O_3 combination yielded excessive sodium in the exhaust.

TABLE 1. THEORETICAL FORMULATION PROPERTIES

T3500

Number	Composition, wt.-%	Density, g/cc	Weight Yield, %	Volumetric Yield, g-%/cc	-ΔH, cal/g
1	65 NaN_3 35 ZrO_2	2.425	38.4	93.1	108
2	60 NaN_3 40 ZnO	2.527	38.8	98.1	122
3	60 NaN_3 40 MnO	2.482	36.4	90.3	135
4	60 NaN_3 40 Cr_2O_3	2.484	34.4	85.5	182
5	65 NaN_3 35 TiO_2	2.276	38.5	87.7	185
6	60 NaN_3 20 Fe_2O_3 20 Al_2O_3	2.418	36.6	88.8	192
7	60 NaN_3 40 Fe_2O_3	2.485	38.8	96.4	198
8	60 NaN_3 40 NiO	2.645	38.8	102.6	237
9	54 NaN_3 36 Fe_2O_3 10 $(COOH)_2$	2.411	34.5 (44.9)	83.3 (118.8)	248 (162)

NOTE: ( ) = nonequilibrium

This reduces to four the number of systems cooler than the Fe_2O_3 baseline; those consisting of NaN_3 with ZnO, MnO, Cr_2O_3, or TiO_2. Formulation No. 9 from table 1 is potentially cooler than Fe_2O_3 alone only if nonequilibrium combustion occurs.

A theoretical criteria also to be considered with temperature is the product of density and gas yield since this relates to compact packaging of the gas generator. As shown in table 1, this efficiency-type number approaches 100 g-%/cc for the better systems. Since the weight percent yield is nearly constant

for many systems, the density of the compacted grain is most important. The high density of formulation No. 8 makes it attractive if the gas can be cooled by some auxiliary means.

2.1.2 Computerized Equilibrium Calculations

A reaction flame temperature and product concentration under varying conditions of pressure, temperature, etc. can be calculated accurately using CSD-developed computer programs. The computer calculations assume that complete thermodynamic equilibrium takes place during the reaction; this condition may be approached in the real flight grain configuration but not necessarily attained.

Figure 1 illustrates the results obtained from computer calculations for various oxidizers. (The calculations are summarized in appendix A.) Most of these combinations were estimated by the method described above; the general order is the same by both calculation techniques (shown in table 1). The heats of formation of the various stable nitrides and oxides were obtained from the JANNAF tables or from the chemical literature. In figure 1, the points noted as "stoichiometric" are those compositions corresponding to the formation of either the freemetal (as in the case for Mo, No, Fe, and Zn) or the nitride (for Al, Ti, Cr, Mr, and Zr), and complete conversion of the NaN_3 to Na_2O and N_2.

In compounding gas generator formulations, clean nonreactive exhaust products are obtained by using more oxidizer than required for stoichiometric balance. This generally establishes the useful range of azide concentration between 60 and 70 wt.-% for most formulations.

General experience has shown many formulations to be difficult to ignite when their theoretical flame temperature is below 1,300° to 1,400°F. This does not eliminate the cool oxidizers shown in figure 1 (such as ZrO_2, ZnO, and MnO) but limits their consideration when low temperature ignitions are required. However, these cool oxidizer formulations can be blended with warmer formulations to yield an overall usable system cooler than the previously developed baseline.

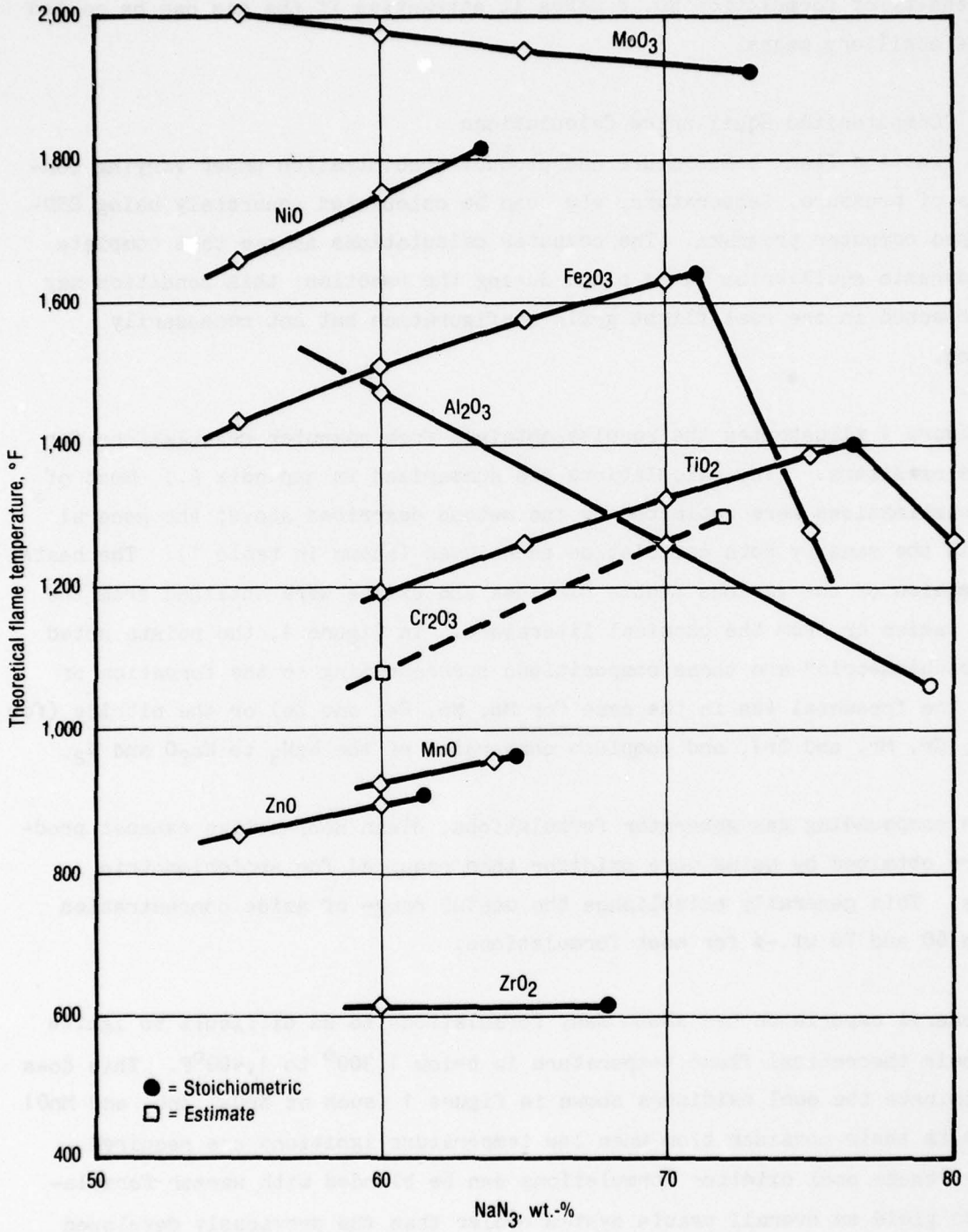

Figure 1. Theoretical Flame Temperatures

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Another generally observed feature used to select formulations from theoretical calculations is the empirically established relationship between gas temperature and burning rate. With few known exceptions, lower temperature mixtures produce lower burning rate and vice versa. This is an effect acknowledged in other combustion systems where the thermal feedback from the gas to the solid phase is credited with being a major driving force in the reaction. The known exceptions, presumably due to nonequilibrium reactions, are for hot systems having low burning rate, but no evidence has been found for a low flame temperature formulation producing a high burning rate.

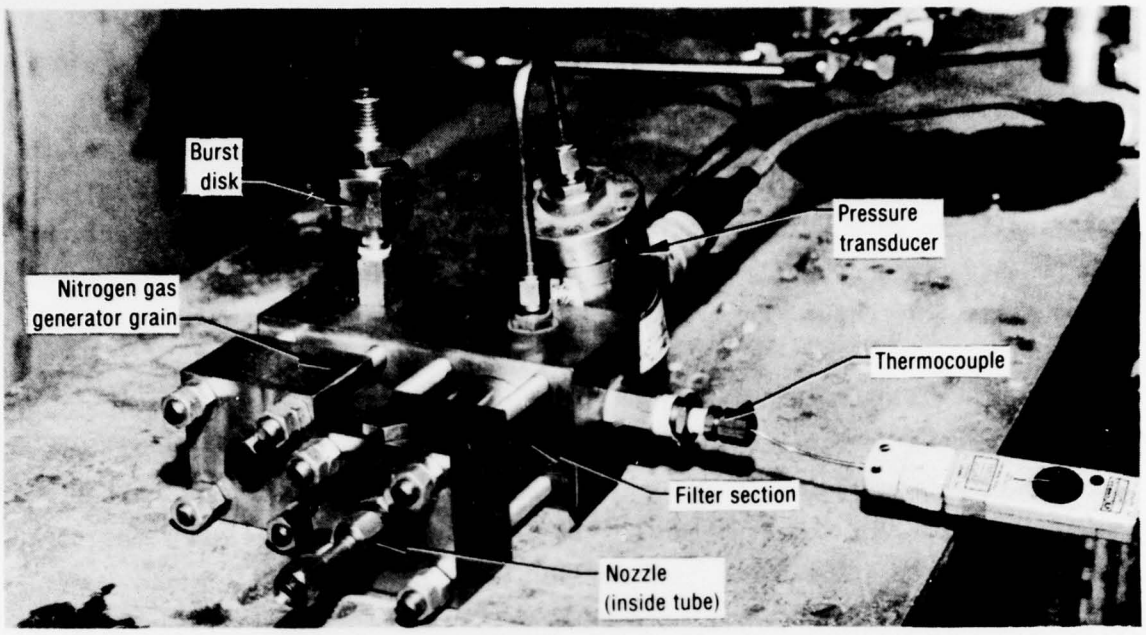
2.2 GAS GENERATOR CHARACTERIZATION TESTS

During the development and characterization phase of this contract 49 tests were conducted involving 19 different formulations using six individual oxidizers. In addition, another six tests were conducted on the final formulation as conformation tests (see section 5.0). Within these tests, many were used to develop a low gas temperature formulation while achieving a satisfactory burning rate. A set of tests was completed to investigate processing aids which would lead to little or no density variations within a pressed grain. Other tests evaluated the materials present in the exhaust gas and some tests gave preliminary information on the effect of temperature on burning rate. All of these tests are discussed in the following paragraphs. The combustion tests are summarized in appendix B.

2.2.1 Temperature/Burning Rate Tests

Development testing of low temperature gas generator formulations was conducted in two different types of test motors. Figure 2 shows the two test configurations. The hardware used to measure burning rate and relative temperature is shown in figure 2(a) and the hardware used to measure the true gas exhaust temperature in a realistic flight grain configuration is shown in figure 2(b). Flight grain testing was not performed until the final gas generator formulation had been determined using the burning rate motor.

A series of 33 tests was conducted to verify temperature-burning rate interaction for a number of formulations. Test No. 170 was a baseline measurement



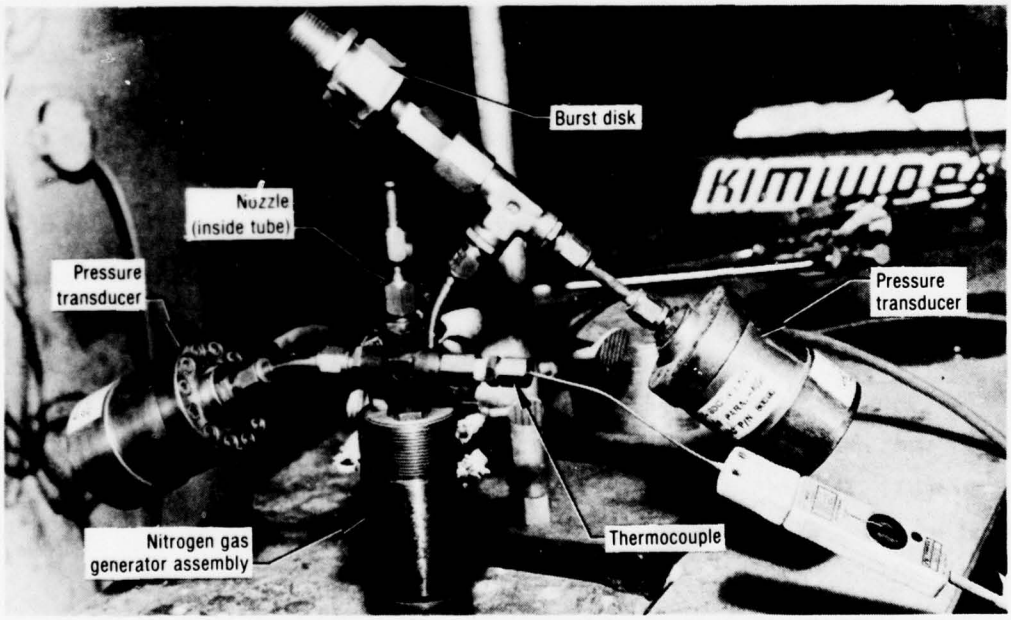


Figure 2. Motor Configurations for Combustion Tests

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for the fuel formulation used in the previous high acceleration gas generator contract (UTG-F60; see appendix B). Here the exhaust temperature was quite warm, reaching 924°F in less than 3 sec of burntime. In an attempt to produce cooler gas, test Nos. 171 through 176 examined four new formulations using MnO, ZnO, and Cr_2O_3 oxidizers. These formulations calculated much cooler but did not sustain combustion under the conditions tested. This effectively eliminates the three candidates as the sole oxidizer for a low temperature propellant system.

Test No. 173 consisted of standard 60% NaN_3/40% Fe_2O_3 formulation but contained 10% oxolic acid. This mixture would be cool if the acid decomposed during combustion and the products did not recombine. The test results suggest a strong recombination of acid products as shown by the high temperature measured and the gas yield being less than anticipated. This is a case showing near equilibrium reaction in a complex combustion system.

Test Nos. 177 and 178 were a further attempt to use Cr_2O_3 oxidizer by increasing the azide concentration to the stoichiometric point of 72 wt.-% (see figure 1). However, the reaction would not sustain after strong igniter stimulus, so consideration of this oxidizer was abandoned. Test Nos. 179 and 180 employ the concept of mixed oxidizers to achieve combustion and low combustion temperatures. Both MnO and ZnO were found to be usable when mixed with Fe_2O_3; intermediate temperatures were obtained during the reactions. This success was duplicated in the same theoretical temperature regime by using of TiO_2 and Fe_2O_3 in test Nos. 181 and 182.

A broader range of temperatures was obtained in test Nos. 183, 186, and 188 by the use of MoO_3. This oxidizer produces warmer N_2; it was tested alone and mixed with both MnO and ZnO. As when these materials were mixed with iron oxide, the MnO formulation gives a slightly lower temperature than the ZnO counterpart. The use of MoO_3 seemed to offer no advantages over the use of Fe_2O_3, thus work with this oxidizer was suspended.

The results obtained indicated the optimum formulations would contain either TiO_2 or a Fe_2O_3/MnO mixture. An attempt to cool the TiO_2 system by

adding ZnO was not successful as the combination would not sustain combustion; however, 70% NaN_3/30% TiO_2 formulations worked well and provided cool gas at a reasonable burning rate. The remainder of the burning rate tests optimized the Fe_2O_3/MnO oxidizer ratio to produce the desired product gas.

From the initial 19 formulations investigated for burning rate and gas temperature, two formulations evolved as potentially meeting the contract requirements. These formulations are 70% NaN_3/30% TiO_2 and 63.75% NaN_3/26.25% Fe_2O_3/10.00% MnO. This latter mixture corresponds to 75% of 65% NaN_3/35% Fe_2O_3 plus 25% of 60% NaN_3/40% MnO; these two formulations are shown in figure 1. In repeated tests, the TiO_2 mixtures burned 100° to 200°F hotter than the MnO formulation; also, the TiO_2 grains were found to be slightly more difficult to fabricate. Table 2 lists the theoretical properties of the two candidate formulations.

2.2.2 Processing Techniques

Two techniques have evolved which aid in the pressing and fabrication of azide-containing nitrogen gas generators. The first technique involves various grinding options to reduce particle size and promote mixing. The other technique stresses additives to the formulation to facilitate powder handling. These techniques are discussed in the following paragraphs.

2.2.2.1 Grinding and Mixing

A series of 10 grains were fabricated under various conditions and their density was measured. Density was selected as the variable of interest in order to promote a greater gas yield per unit volume and also to reduce any density gradient between the pressed segments down the length of the grain. The 10 grains used in this study were of the 70% NaN_3/30% TiO_2 formulation since from previous work it had a low density but was of interest for cool gas generation. Table 3 summarizes the test results.

The results show a steady improvement in compacted density as a function of grinding or mixing time. In most cases both the oxidizer and azide fuel were found to have a particle size less than 3 to 5 μm after 24 hr of grinding.

TABLE 2. THEORETICAL PROPERTIES OF NITROGEN GAS GENERATORS

T3501

Property	Formulation	
	UTG-T70	UTG-FM64
Composition	30% TiO_2 70% NaN_3	10.00%/MnO 26.25% Fe_2O_3 63.75% NaN_3
Flame temperature, ^oF	1,323	1,484
Density, g/cc	2.200	2.410
Weight yield, %	41.5	41.2
Volumetric yield, g-%/cc	91.2	99.3

TABLE 3. EFFECT OF GRINDING/MIXING ON GRAIN DENSITY (70% NaN_3/30% TiO_2)

T3502

Number of Grains Tested	Average Density, g/cc	Grind/Mix Time, hr	Crystalline Density, %
2	1.761	0	79
4	1.802	7	81
4	1.841	45	83

The grinding was done in various size ball mills using a constant grind-media-weight-to-jar-volume ratio. Best results were obtained using an inert organic liquid carrier (usually methylene chloride).

2.2.2.2 Processing Additives

Three processing additives at two concentrations were tested to aid compaction and to increase density. The six grains were fabricated in an identical manner as other baseline control grains using the 70% NaN_3/30% TiO_2 formulation. The aids tested were submicron SiO_2 powder, submicron MoS_2 powder, and TFE spray powder.

The two dry powders were mixed with each formulation and pressed. The fumed SiO_2 is commonly used to control and promote powder flow; the MoS_2 powder is often used to lubricate various surfaces. TFE was sprayed directly onto the formulation mixture and allowed to dry. Repeated spraying, mixing, and drying allowed various weights of fine TFE to be applied to the propellant powder. Pressing was done after the mixture was thoroughly dried.

With these three additives tested, there was no noticeable increase in grain density or ease of grain fabrication. No significant effect on gas generator production was noticed using the formulations containing the tested materials. There did seem to be a catalytic effect on burning rate (and/or gas temperature) due to incorporation of the submicron SiO_2 but this effect was not investigated further.

An effective aid to increasing density was discovered when the steel motor cases were lined with the spray TFE. Two thicknesses of TFE film were applied to the cases and ease of fabrication and density were monitored. An example is the case where the density changed from an average of 1.841 g/cc (table 3) or 83% of crystalline density to 1.953 g/cc or 88% of crystalline density. The TFE coating also eased the removal of the punch after each pressed section was completed. Little pressure variation during combustion was observed as the grain burned from segment to segment. This implies a fixed density throughout the grain length.

2.2.3 Exhaust Solids Characterization

Four motor tests were conducted to determine the characteristics of solids entrained in the exhaust of two different formulations. The two formulations tested were 70% NaN_3/30% TiO_2 and 63.75% NaN_3/26.25% Fe_2O_3/10.00% MnO which were the two final formulations considered to meet project requirements. These two mixtures also represent significantly different oxidizers. Each test was conducted as shown in figure 2(b). Output gas from the gas generator was passed through 100 $in.^2$ of 0.8 μm porosity filter media. The entire motor gas discharge was filtered. Following the tests, samples were cut from the filter at the outer edge, in the center, and half-way between these two. The filter samples were analyzed using an SEM.

Photos from the SEM are shown in figure 3. In all these photos the magnification is 1,000 times and 1 mm = 1 μm. The top photo shows the center sample from a test using the TiO_2 oxidizer formulation. The small particles have dimensions of about 4 by 7 μm with some spherical particles being about 2 μm in diameter. In the two tests using the TiO_2 oxidizer only a few particles were found having any dimension greater than 10 μm. The bottom photo shows the center sample from a filter used with the Fe_2O_3/MnO formulation. Comparing the middle and bottom photos shows more particles to emanate from the TiO_2 system than from the Fe_2O_3/MnO mixture. The few particles noted in the bottom photo appear to be spherical with a diameter of 2 to 3 μm.

The conclusion from viewing all the SEM scans (four scans per test and four tests) is that both systems are relatively clean; this implies that the sintered metal filter being used is sufficient. The metal filter used in these tests has nominal 10 μm pores with a pore distribution from 5 to 15 μm. A finer filter can readily replace the one in use with no dysfunction anticipated; an increase in pressure drop across the filter can be accommodated.

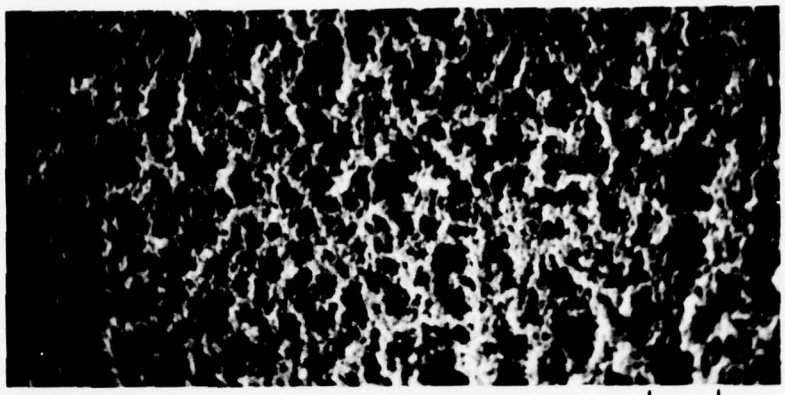
2.2.4 Gas Generator Thermal Sensitivity

Four tests were conducted to determine the preliminary ambient temperature sensitivity of one candidate formulation. The formulation selected for testing was 63.75% NaN_3/26.25% Fe_2O_3/10.00% MnO; this mixture most closely meets the desired specifications while having the lowest exhaust temperature. The results of these four tests and two other tests at room temperature give preliminary indications of thermal effects on burning rate; final thermal effects were determined in full size flight configured hardware.

Figure 4 and table 4 show the results of the temperature sensitivity tests. The experimental data shown in figure 4 are curve-fit to yield the equations in table 4. The two temperature sensitivity parameters, π_k and σ_p, are calculated according to the following definitions:

$$\pi_k = \left(\frac{\delta \ln P}{\delta T}\right)_k$$

$$\sigma_p = \left(\frac{\delta \ln r}{\delta T}\right)_p$$



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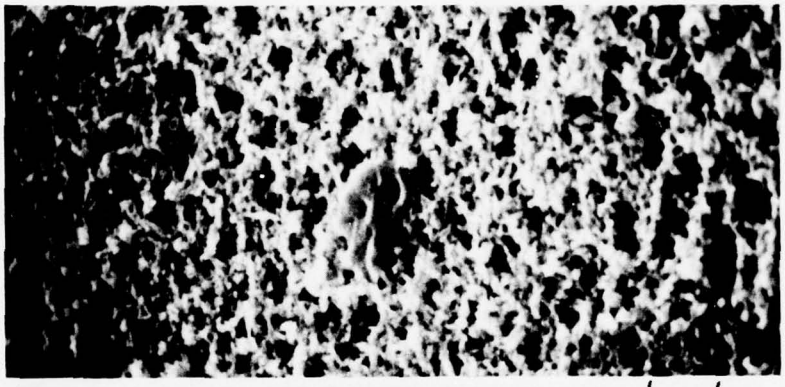
a) Unused Filter

10 μm



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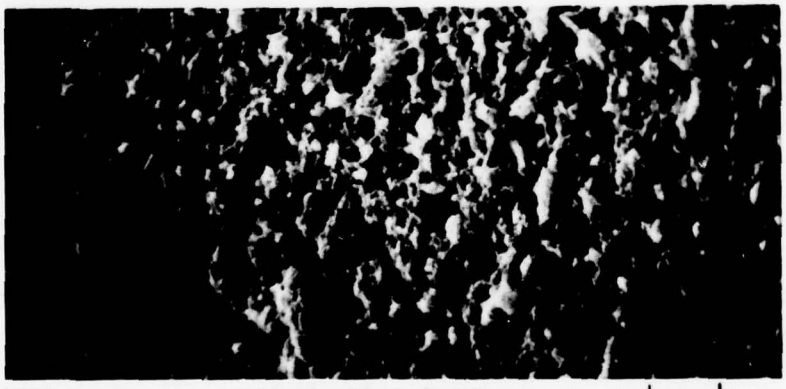
b) TiO_2 Oxidizer

10 μm



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c) Fe_2O_3/MnO Oxidizer

10 μm

Figure 3. Exhaust Particulates

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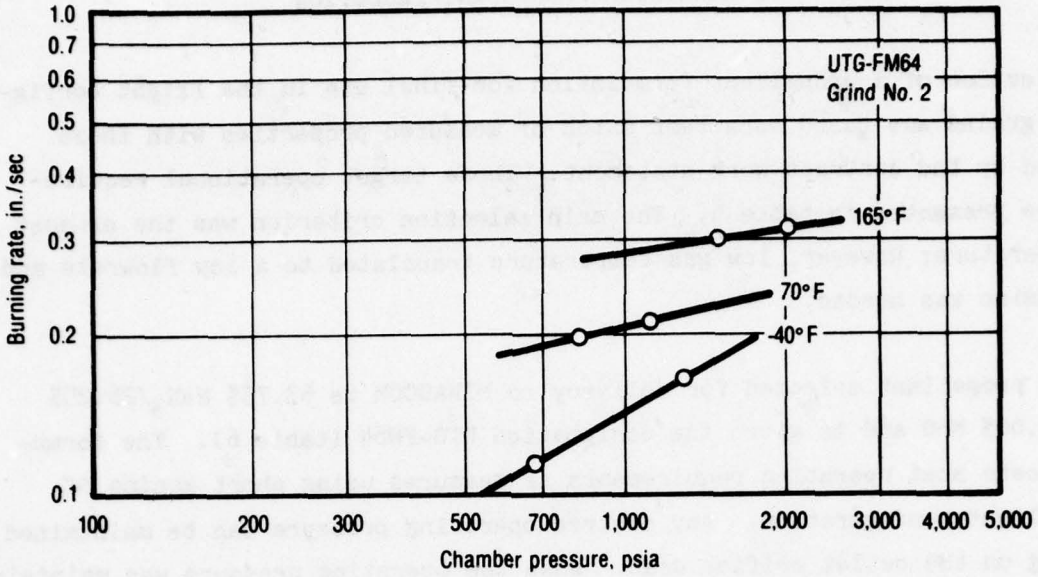

Figure 4. Preliminary Thermal Sensitivity

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TABLE 4. PRELIMINARY THERMAL SENSITIVITY PARAMETERS
(UTG-FM64, Grind No. 2)

T3503

Temperature, °F	Burning Rate, in./sec
-40	$r = 0.145\ (P_c/1{,}000)^{0.563}$
70	$r = 0.205\ (P_c/1{,}000)^{0.237}$
165	$r = 0.285\ (P_c/1{,}000)^{0.129}$

$\pi_k = 0.54\%/^{\circ}F$
$\sigma_p = 0.34\%/^{\circ}F$

The relatively high value of $\pi_k = 0.54\%/^{\circ}F$ is due to the limited energy release associated with the combustion of this particular formulation. The π_k is lower for higher temperature formulations.

3.0 GAS GENERATOR PROPELLANT SELECTION

Selection of a propellant formulation for final use in the flight configuration grains was based on a best match of measured properties with those suggested by the contract work statement. Those target operational requirements are presented in table 5. The main selection criterion was the exhaust gas temperature; however, low gas temperature translated to a low flowrate and a compromise was needed.

The propellant selected for delivery to MIRADCOM is 63.75% NaN_3/26.25% Fe_2O_3/10.00% MnO and is given the designation UTG-FM64 (table 6). The formulation meets most operating requirements as measured using short grains of nearly flight configuration. Any desired operating pressure can be maintained depending on the outlet orifice used. When the operating pressure was maintained at 1,000 psia the gas generators' flowrate exceeded the target value of all temperatures above 70°F. Burntime equalled or exceeded 30 sec at all grain temperatures. The outlet gas temperature was less than 550°F for at least 20 sec at grain temperatures less than 85°F. Gas particulate matter was discussed earlier and met all operating requirements. The gas generator weight and size were minimized within the restraints of other requirements; system diameter remains the same as for the previous effort to allow use of available tooling. Ignition delay was considerably less than 0.2 sec at all grain temperatures. The design changes required for 25,000-g acceleration is discussed in the following section.

TABLE 5. SYSTEM OPERATING REQUIREMENTS

T3504

Pressure, psia	$900 < P_c < 1,100$
Flowrate, lb/sec	≥ 0.011
Burntime, sec	≥ 30
Gas temperature, °F	≤ 550
Gas particulate matter, m	≤ 10
Operating temperature, °F	−40 to 165
System size, in.	≤ 13 (length) by ≤ 2 (diameter)
Ignition delay, sec	≤ 0.2
Acceleration, g	$\leq 25,000$ (longitudinal)
	$\leq 2,500$ (other axis)

TABLE 6. NITROGEN GAS GENERATOR (UTG-FM64)

T3505

Composition, wt.-%

63.75% NaN_3
26.25% Fe_2O_3
10.00% MnO

Grain Properties

Density (measured), g/cc	2.15 to 2.20
Impact sensitivity, kg-cm	>150
Friction sensitivity	Negative
Shipping classification	Flammable solid, class B poison

Combustion Properties

Temperature (theoretical), °F	1,485
Temperature (measured), °F	550
Burning rate (1,000 psia), in./sec	0.20
Pressure exponent	0.36
Pressure range tested, psia	650 to 2,000
Temperature sensitivity (π_K), %/°F	0.43
Temperature sensitivity (σ_p), %/°F	0.27
Temperature range tested, °F	-40 to 165

Theoretical Gas Generation Properties

Total gas evolution, wt.-%	41.2
Gas composition, wt.-%	99.98 N_2
Total solid residue, wt.-%	58.8
Solid composition, wt.-%	51.7 Na_2O
	30.9 Fe
	0.4 FeO
	17.0 MnO

4.0 DESIGN OF FLIGHT TEST UNIT

The design of the flight-test gas generator unit is nearly identical to the system delivered under the previous contract. The following sections discuss the basic design factors and differences of the two systems.

4.1 GAS GENERATOR DESIGN

The 1.5-in.-diameter basic gas generator design is shown in figure 5 in an assembly view. The case is constructed of 4130 steel tubing, 1-3/4 in. diameter by 0.120-in. wall with a welded steel base. The gas generator grain is pressed into the case and burns as an end burner from the top surface to the bottom. The filter case attaches to the grain case by mating threads and is sealed by a Viton O-ring gland seal. The grain's retention disk is compressed between the inside of the filter case and the grain surface to completely restrain the surface. The filter assembly consists of a perforated metal tube, 2 g of compressed No. 000 steel wool, and a sintered stainless steel filter tube. The latter is pressed into the filter case, the fit providing the gas seal between the filter tube and filter case for the bottom portion of the filter. The perforated tube is held on a shoulder in a close fitting hole at the bottom of the filter case. The steel wool is compressed in the annular space between the perforated tube and the filter tube. The top portion of the filter assembly is held together by a steel spacer into which the filter tube is pressed. The perforated tube is held on the centerline in a close fitting hole which comprises the ID of the spacer. A Viton O-ring face seal is provided on the top surface of the spacer which prevents gas leakage between the end of the filter assembly and the aluminum end plug. The end plug is threaded into the end of the filter case and gas leakage is prevented by a Viton O-ring gland seal. AN ports are provided on the end plug for the gas outlet port, the ignition squib, and a port for monitoring filter pressure drop or pressure relief. The latter port is not required for operating the gas generator, but was included for test purposes. The ignition squib fires down through the open center of the filter assembly, through the grain retention disk, and ignites the grain surface. The generated gas passes radially through the holes in the perforated tube, through the steel wool, and radially through

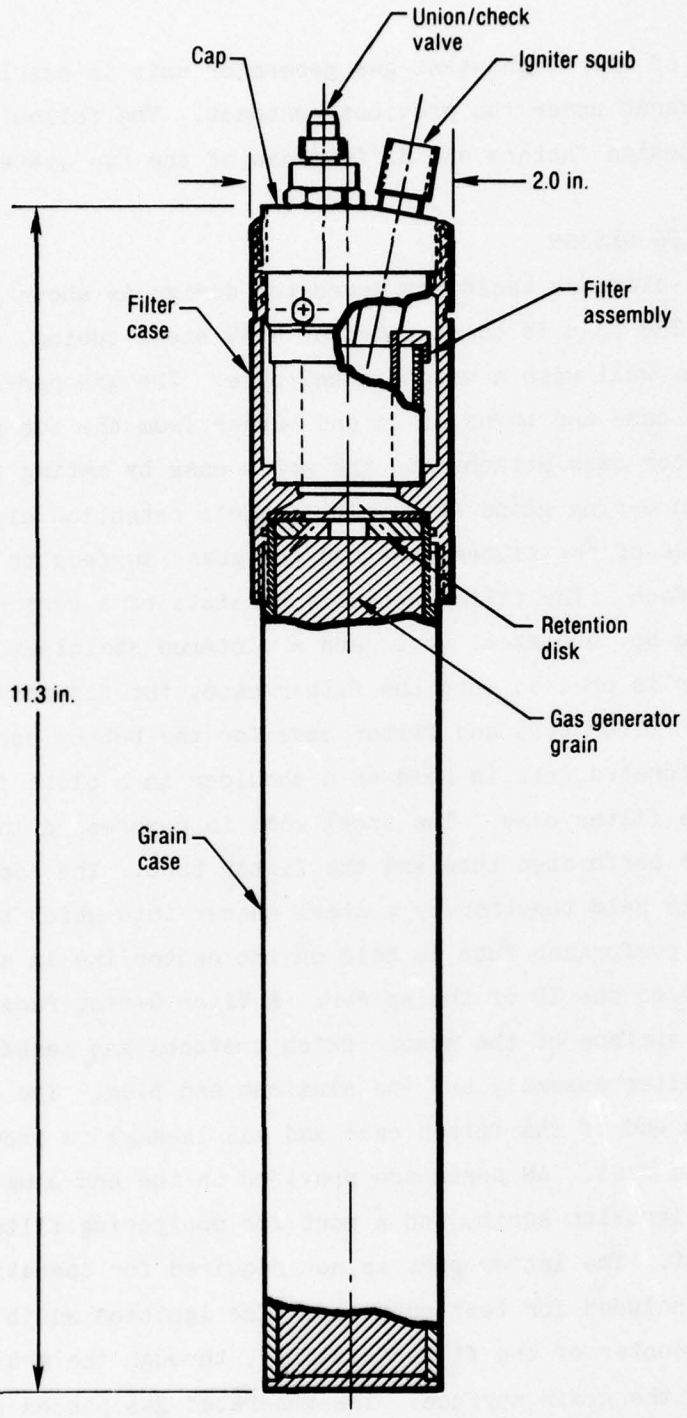

Figure 5. Assembly View of Nitrogen Gas Generator

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the sintered metal filter tube. The filtered gas flows around and up the annular space between the filter tube and the filter case and enters a drilled hole in the end plug which leads to the gas outlet port.

4.2 STRESS CONSIDERATIONS

The major design consideration which differs from the previous contract effort is the increase in acceleration loading. The previously supplied gas generator units were designed for 10,000-g setback and a 2000-g set forward; current requirements are for a 25,000-g setback and a 2,500-g shock in other directions. Table 7 presents a component weight breakdown and a summary of loads required and designed.

The acceleration load represented by the combination of gas generator grain and case is the only structural area that was modified for the higher g level. In this case, the load was extended over a larger area, allowing a higher total load level. This was done by using a larger washer to support the load from the grain through the surface retention disk. Also, a 30% higher strength steel was used to fabricate the filter case. The threads provide a safety margin during setback and readily carry the entire 2,500-g load during set forward.

The setback load of filter assembly and aluminum plug at the top end of the generator must be carried by the aluminum threads. Analysis shows that these threads will support 13,400 lb. This yield point is enough for both set forward and set backward. The setback load of the entire gas generator assembly can be supported by the shoulders on the cannister adapter; set forward is borne by the threads.

TABLE 7. GAS GENERATOR ACCELERATION LOADS

T3506

Component	Weight, lb		Design Load, lb
	1 g	25,000 g	
Grain	1.24	31,000	Restrained
Case + grain	2.77	69,200	76,800 (washer) 23,300 (threads)
Filter case	0.87	21,750	23,300 (threads)
Aluminum cap	0.22	5,500	13,400 (threads)
Filter element	0.08	2,000	Filter assembly
Filter tube	0.05	1,250	
Filter sleeve	0.05	1,250	
Cap + filter assembly	0.40	10,000	13,400 (threads)
Gas generator assembly	4.04	101,000	150,000 (shoulders) 58,100 (threads)

5.0 CONFORMANCE TESTS

A series of six full-scale tests were conducted using the flight design gas generator system discussed earlier. These tests were used to demonstrate the conformance of the nitrogen gas generators to the requirements listed previously (table 5). The following sections discuss the test setup, procedures, and results.

5.1 TEST SETUP

The test motors were manufactured and assembled according to drawing No. T7801; a copy of this drawing is included as an enclosure to this report. The gas generator grains were fabricated, measured, and weighed 1 to 2 weeks prior to testing.

Figure 6 shows a fully assembled flight gas generator in the firing configuration used for the conformance test. The filtered nitrogen gas exits vertically through the tube at the top of the gas generator; the exit nozzle is contained in the exit tube. The temperature and pressure of the filtered nitrogen were measured just upstream of the sonic choke. The temperature was measured with a 1/16-in.-diameter, Inconel-sheathed chromel-alumel thermocouple. The thermocouple signal was conditioned before recording on a CEC model No. 124 oscillograph using a CEC No. 7-342 galvanometer. The gas pressures were monitored with Taber model No. 206-SA strain gage pressure transducers. The output was recorded with the same type of equipment as the temperature signal. A burst disk assembly using a 1,900-psi burst disk was installed in the line to the precharge port to protect the instrumentation and hardware in the event of failure of a component.

5.2 TEST PROCEDURES

The gas generator assemblies were thermally soaked for at least 80 hr in a thermostatically controlled oven at 165°F and an electronically controlled freezer at -40°F. Each motor was conditioned with its igniter squib and thermocouple in place leaving only the burst disk, pressure transducers, and sonic choke to be installed before the test. A vacuum was pulled on the low

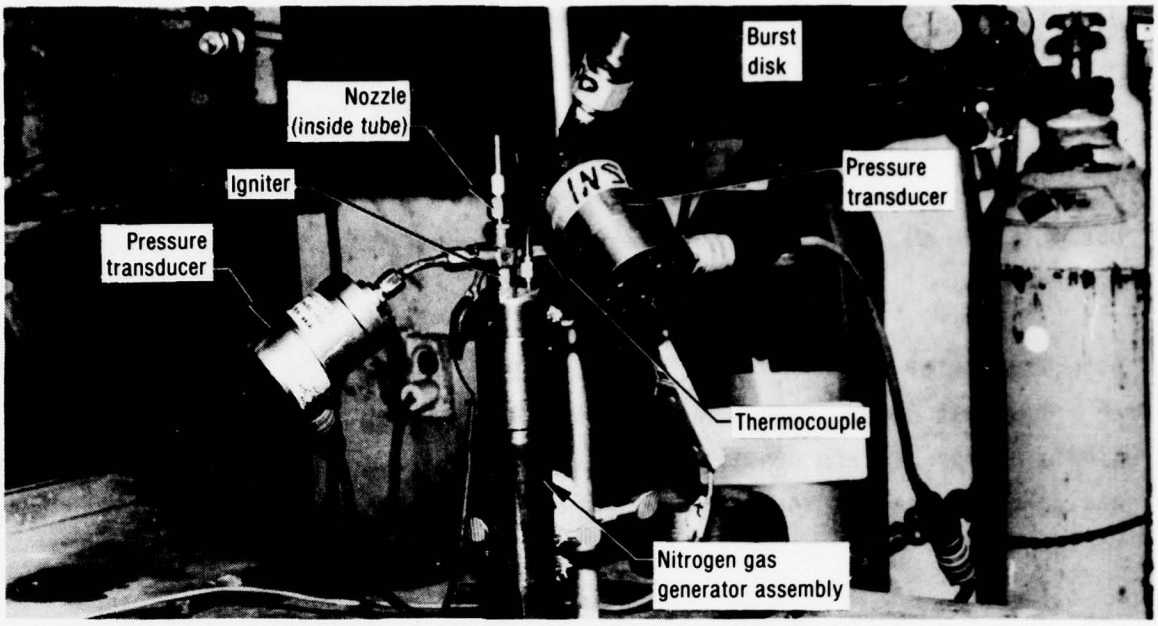

Figure 6. Test Configuration of Flight Gas Generator

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temperature units followed by pressure equalization with dry nitrogen to avoid the possibility of ice formation within the unit.

The instrumentation leads were connected to the transducers and the transducers were electrically zeroed and calibrated before each test. The calibration voltage levels were recorded on the oscillograph as were timing and event markers.

5.3 CONFORMANCE TEST RESULTS

Six conformance tests were conducted at three ambient temperatures to determine the characteristics of full size gas generators. A summary of test results is listed in table 8; further details are listed in appendix B. Oscillograph traces of all conformance tests are shown in appendix C.

The conformance test data confirm the data generated during the characterization tests and expand the information available for UTG-FM64. The measured ignition delays are less than 0.12 sec even at an ambient temperature of -40°F

TABLE 8. CONFORMANCE TESTS

T3507

	Test Number/Grain Number					
	223/3	224/5	225/6	226/4	227/1	228/2
Grain temperature, °F	70	70	165	165	-40	-40
Throat diameter, in.	0.031	0.026	0.037	0.035	0.023	0.023
Burntime, sec	46.83	-	36.68	37.24	59.90	59.26
Pressure, psia	820	-	795	900	1,060	1,015
Burning rate, in./sec	0.181	-	0.233	0.230	0.141	0.143
Ignition delay, sec	0.06	0.08	0.03	0.03	0.11	0.12
Maximum gas temperature, °F	737	-	742	-	598	608
Time to 550°F, sec	20	-	13	-	42	45
Weight flowrate, lb/sec	0.0102	-	0.0135	0.0134	0.0081	0.0080
Volume flowrate, ft^3/min	0.308	-	0.441	0.386	0.141	0.145
Grain density, $lb/in.^3$	0.0778	0.0783	0.0791	0.0798	0.0791	0.0770

which is well below the target delay of 0.20 sec. Ignition delay is defined as the time from electric signal application to 70% of nominal system pressure.

All gas generators operated satisfactorily with one exception. In test No. 224 (a 70°F test) the gas generator system was incorrectly assembled allowing the gas to exit directly through the outlet orifice without being filtered. The lack of filtering caused the orifice to become plugged leading to overpressurization and rupture of the burst disk. The combustion terminated after 3.7

sec with no further gas evolution. This test shows that the filters are effective in the properly assembled units.

The burning rates measured during the conformation tests were lower than that assumed from the characterization tests (see figure 4). At 165°F the extrapolation of earlier data was 14% high leading to low pressures during conformation. The original 70°F data was high also, but to a lesser degree (2%). At -40°F there was no change in burning rate. This reinterpretation of burning rate data (figure 7) leads to lower σ_p and π_k values. Table 9 lists the burning rate and thermal data for UTG-FM64 using combined conformation and characterization tests and curve fitting all results. π_k is an average value and reflects a value of 0.34%/°F from 40° to 165°F; below 40°F the value rises dramatically to 0.58%/°F.

To meet the target flow rate requirement of 0.011 lb/sec at all temperatures, a burning rate of 0.20 in./sec is needed in the present 1.50-in.-diameter hardware. Table 9 shows this condition is met at 70°F and above if the gas generator pressure is 1,000 psia or more. As the pressure or temperature decreases, the flowrate falls below 0.011 lb/sec. This deficiency can be corrected at all ambient temperatures by enlarging the grain from 1.50 in. to 1.75 in. in diameter. The burntime exceeded the target value of 30 sec at all temperatures which allows the grain to be shortened from 8.55 in. to 7.44 in., thus reducing the gas generators overall length and weight.

The maximum gas temperature obtained during these conformance tests averaged 200° to 300°F cooler than tests of the previous effort[4]. Nevertheless, this large reduction in exhaust gas temperature is not sufficient to maintain the gas temperature under 550°F for 30 sec at all soak temperature conditions. Table 8 lists the times required for the outlet gas to reach 550°F in flight-type hardware; only those grains at -40°F provide less than 550°F gas for over 30 sec. While further improvements in providing lower combustion temperatures can be realized, it appears more practical to consider external cooling devices (active or passive) if required by the application.

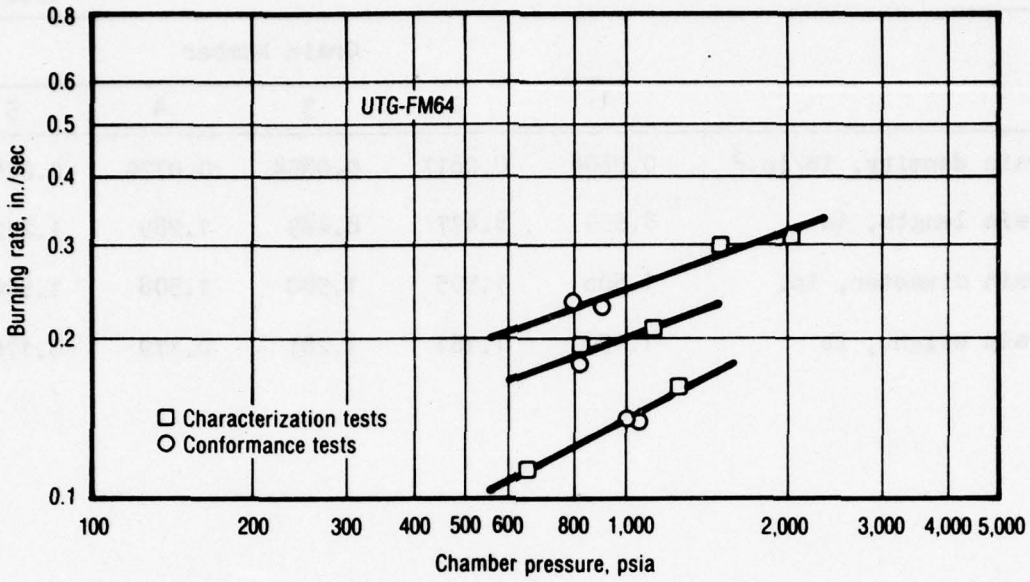

Figure 7. Thermal Sensitivity of Burning Rate

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TABLE 9. THERMAL AND BURNING RATE DATA
(UTG-FM64)

T3508

Temperature, °F	Burning Rate, in./sec
-40	$\dot{r} = 0.142\ (P_c/1{,}000)^{0.536}$
70	$\dot{r} = 0.202\ (P_c/1{,}000)^{0.364}$
165	$\dot{r} = 0.248\ (P_c/1{,}000)^{0.360}$

$\pi_k = 0.43\%/^{\circ}F$
$\sigma_p = 0.27\%/^{\circ}F$

5.4 DELIVERY OF HARDWARE

Five gas generator systems were fabricated and delivered to MIRADCOM. The systems were built and assembled per drawing No. T7801; each system was complete with filter, igniter, etc. Two of the systems delivered were designed for 4-sec operation while the other three systems were designed for 30-sec operation. Data for each delivered grain is given in table 10.

TABLE 10. DELIVERED GAS GENERATORS
(UTG-FM64, Batch No. 4)

T3509

	Grain Number				
	1	2	3	4	5
Grain density, lb/in.^{3}	0.0808	0.0817	0.0854	0.0776	0.0788
Grain length, in.	8.559	8.477	8.489	1.289	1.212
Grain diameter, in.	1.506	1.505	1.500	1.508	1.506
Grain weight, lb	1.192	1.161	1.281	0.179	0.170

6.0 CONCLUSIONS

The following conclusions are based on experimental results developed during this effort; they use other information developed in the previous program, contract No. DAAH01-75-C-0801[4]. The combined data from these two programs show the extent of development of a unique low temperature nitrogen gas generator for use as a compact storable gas supply for tube-launched guided projectiles.

The conclusions are the following:

A. The present overall gas generator design is expected to meet operational requirements, including a 25,000-g environment.

B. The gas generator produces an exhaust which is free of particles except for a very small number of particles in the 2 to 3 μm range.

C. Under most operating conditions, the exhaust of the test formulation does not exceed the 550°F requirement except near end of burn. Achieving the limit with grains conditioned to 165°F presently appears to be problematical unless external cooling devices are used.

D. Improvements in achieving a more neutral pressure-time profile were demonstrated. Further improvements are likely to be based on achieving higher density (more uniform) grain compaction.

E. The lower exhaust temperature results in a temperature coefficient of pressure (π_K) somewhat greater than earlier developed nitrogen generating compositions.

F. The ignition transient is within the specified ignition limit at all temperature conditions.

7.0 RECOMMENDATIONS

Based on the successful completion of this and prior high acceleration gas generator efforts, the following items are recommended for further study:

A. Investigate the effects of long term storage on gas generator combustion performance

B. Investigate the effects of temperature cycling and vibration on grain integrity

C. Apply developed processing techniques to produce a grain of higher density and eliminate density variations within the grain

D. Develop combustion catalysts to increase burning rate in low temperature formulations

E. Develop and evaluate a temperature-compensated control device to vary the system's orifice and thereby reduce the quantity of propellant required.

REFERENCES

1. "Nitrogen Gas Generator Fluidics Operation," Interim Technical Report, Phase I, Contract No. DAAA21-74-C-0506, November 15, 1974.

2. "Nitrogen Gas Generator Fluidics Operation," Interim Technical Report, Phase II, Contract No. DAAA-21-74-C-0506, January 30, 1975.

3. "Nitrogen Generator and Filter System," Final Report, Contract No. DAAH03-74-C-0353, October 16, 1974.

4. "Nitrogen Gas Generator Development - CLGP," Final Report, Contract No. DAAH01-75-C-0801.

APPENDIX A

SUMMARY OF COMPUTER CALCULATIONS

SUMMARY OF COMPUTER CALCULATIONS

Composition	Pressure, psia	Temperature, °F	Density, lb/in.^{3}	N_2 Yield, %
63.5 NaN_3/36.5 NiO	1,000	1,815	0.0906	41.0
60.0 NaN_3/40.0 NiO	1,000	1,752	0.0938	38.8
55.0 NaN_3/45.0 NiO	1,000	1,659	0.0989	35.5
60.0 NaN_3/40.0 ZnO	1,000	895	0.0912	38.8
55.0 NaN_3/45.0 ZnO	1,000	852	0.0955	35.5
67.9 NaN_3/32.1 ZrO_2	750	616	0.0830	42.2
60.0 NaN_3/40.0 ZrO_2	750	616	0.0889	36.9
68.0 NaN_3/32.0 ZrO_2	750	616	0.0830	42.3
75.0 NaN_3/25.0 TiO_2	1,000	1,383	0.0769	44.4
70.0 NaN_3/30.0 TiO_2	1,000	1,323	0.0795	41.4
65.0 NaN_3/35.0 TiO_2	1,000	1,259	0.0822	38.5
60.0 NaN_3/40.0 TiO_2	1,000	1,192	0.0852	35.5
80.0 NaN_3/20.0 TiO_2	1,000	1,276	0.0752	48.2
65.0 NaN_3/35.0 MoO_3	750	1,953	0.0847	42.0
60.0 NaN_3/40.0 MoO_3	750	1,978	0.0881	38.8
55.0 NaN_3/45.0 MoO_3	750	2,004	0.0917	35.5
80.0 NaN_3/20.0 Ti_2O_3	1,000	1,291	0.0758	47.8
75.0 NaN_3/25.0 Ti_2O_3	1,000	1,465	0.0784	43.6
70.0 NaN_3/30.0 Ti_2O_3	1,000	1,526	0.0804	40.0
65.0 NaN_3/35.0 Ti_2O_3	1,000	1,503	0.0834	36.8
60.0 NaN_3/40.0 Ti_2O_3	1,000	1,479	0.0866	33.6
63.0 NaN_3/27.0 Fe_2O_3/ 10.0 $(CONH_2)_2$	750	1,824	0.0796	41.6
60.0 NaN_3/40.0 MnO	1,000	922	0.0895	36.2
64.0 NaN_3/36.0 MnO	1,000	956	0.0865	38.6
70.0 NaN_3/30.0 $CaMg(CO_3)_2$	1,000	1,692	0.0747	42.2
70.0 NaN_3/30.0 $CaMg(CO_3)_2$	750	1,683	0.0747	42.3
60.0 NaN_3/40.0 $CaMg(CO_3)_2$	750	1,752	0.0778	36.3
63.75 NaN_3/26.25 Fe_2O_3/ 10.00 MnO	1,000	1,484	0.0871	41.2

APPENDIX B

CHARACTERIZATION TESTS

CHARACTERIZATION TESTS

Number	Formulation, wt.-%	Grain Weight, g	Gas Weight, g	Yield, %	Ignition delay, sec	Grain length, in.	Throat Length, in.
170	60 NaN_3/40 Fe_2O_3	50.68	21.34	42.1	0.03	0.821	0.0320
171	60 NaN_3/40 MnO	47.93	5.47	-	0.03	0.797	0.0320
172	60 NaN_3/40 MnO	61.20	8.91	-	0.03	1.017	0.0225
173	54 NaN_3/36 Fe_2O_3/ 10 $(COOH)_2$	61.99	23.77	38.2	0.02	1.022	0.0320
174	60 NaN_3/40 ZnO	65.39	9.49	-	0.02	1.040	0.0225
175	60 NaN_3/40 Cr_2O_3	52.03	4.73	-	0.02	0.836	0.0320
176	60 NaN_3/40 Cr_2O_3	60.16	9.95	-	0.02	0.966	0.0225
177	72 NaN_3/28 Cr_2O_3	48.04	5.29	-	0.02	0.821	0.0320
178	72 NaN_3/28 Cr_2O_3	53.73	5.65	-	0.02	0.929	0.0320
179	60 NaN_3/20 Fe_2O_3/ 20 MnO	57.36	21.32	37.2	0.03	0.909	0.0320
180	60 NaN_3/20 Fe_2O_3/ 20 ZnO	63.72	24.49	38.4	0.03	1.027	0.0320
181	65 NaN_3/35 TiO_2	70.40	9.07	-	0.02	1.336	0.0225
182	65 NaN_3/35 TiO_2	65.80	27.22	41.4	0.02	1.252	0.0320
183	60 NaN_3/40 MoO_3	59.16	25.86	43.7	0.02	0.934	0.0320
184	60 NaN_3/20 MoO_3/ 20 MnO	59.92	24.95	41.6	0.03	0.949	0.0320
185	60 NaN_3/10 MoO_3/ 30 MnO	65.58	24.04	36.7	0.02	1.076	0.0320
186	60 NaN_3/10 MoO_3/ 30 MnO	70.51	25.40	36.0	0.02	1.100	0.0320
187	65 NaN_3/15 TiO_2/ 20 ZnO	64.18	5.90	-	0.03	1.132	0.0320
188	60 NaN_3/15 MoO_3/ 25 ZnO	74.48	28.58	38.4	0.03	1.188	0.0320
189	70 NaN_3/30 TiO_2	65.14	28.12	43.2	0.02	1.268	0.0320
190	70 NaN_3/29.5 TiO_2/ 0.5 SiO2	65.21	28.12	43.1	0.02	1.248	0.0320
194	70 NaN_3/29.2 TiO_2/ 0.8 TFE	61.42	30.84	50.2	0.03	1.150	0.0320
195	69 NaN_3/29 TiO_2/ 2 TFE	65.28	28.12	43.1	0.03	1.254	0.0320
196	60 NaN_3/30 Fe_2O_3/ 10 MnO	57.79	24.04	41.6	0.02	0.965	0.0320
197	60 NaN_3/25 Fe_2O_3/ 15 MnO	63.57	25.86	40.7	0.02	1.031	0.0320
198	70 NaN_3/30 TiO_2	47.02	19.96	42.4	0.03	0.861	0.0320
199	60 NaN_3/20 Fe_2O_3/ 20 MnO	63.75	25.86	40.6	0.03	1.049	0.0320
200	69 NaN_3/29 TiO_2/ 2 SiO_2	55.14	23.59	42.8	0.03	1.026	0.0320
201	70 NaN_3/29.5 TiO_2/ 0.5 MoS_2	63.15	27.67	43.8	0.03	1.159	0.0320
202	69 NaN_3/29 TiO_2/ 2 MoS_2	62.09	26.76	43.1	0.03	1.117	0.0320
203	60 NaN_3/20 Fe_2O_3/ 20 MnO	63.12	25.40	40.2	0.03	1.027	0.0320

CHARACTERIZATION TESTS

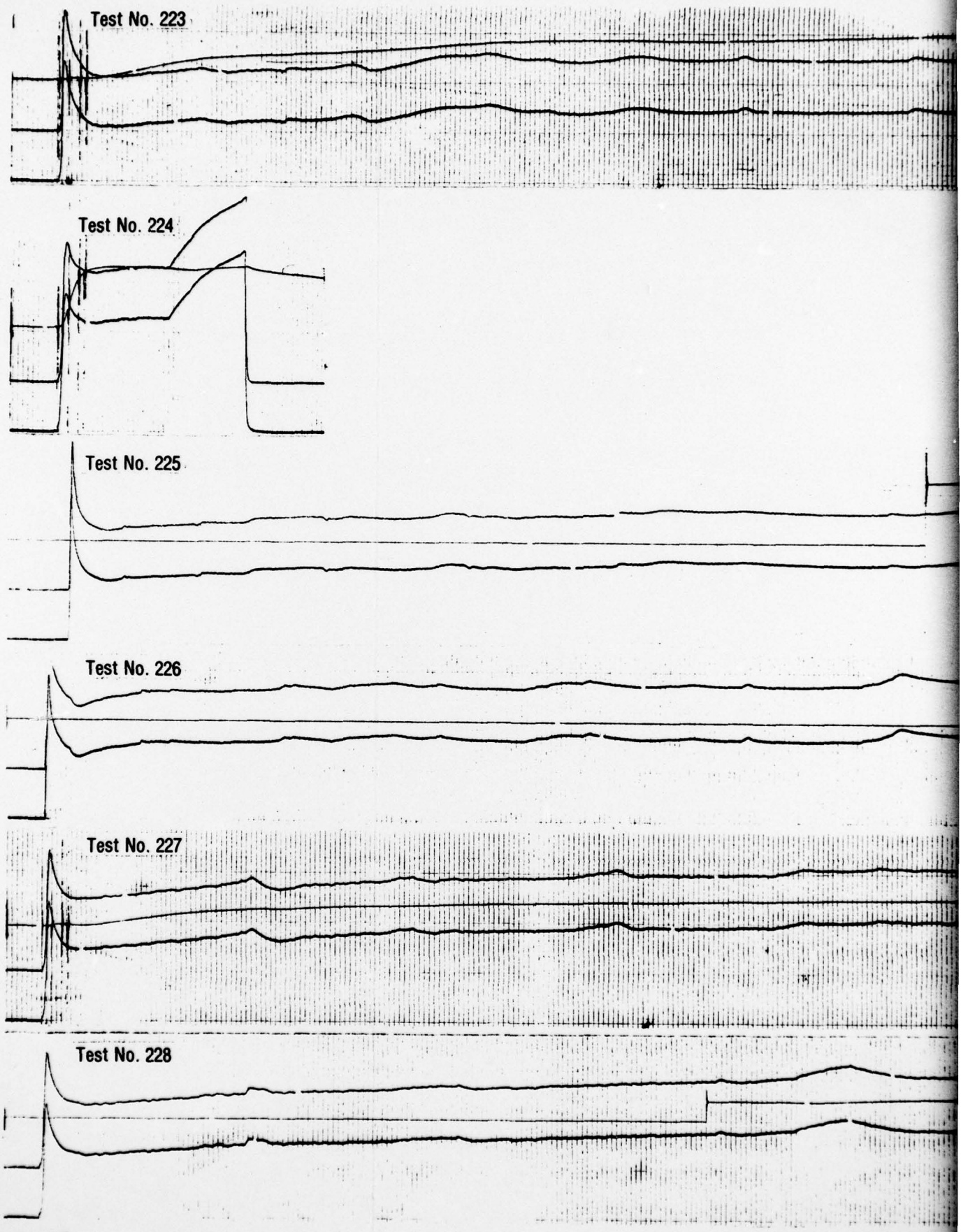
ition lay, ec	Grain length, in.	Throat Length, in.	Burn-time, sec	Burning Rate, in./sec	Pres-sure, psia	Tempera-ture, °F Grain	Gas	Comments
.03	0.821	0.0320	2.73	0.301	785	68	924	Reference formulation
.03	0.797	0.0320	-	-	-	70	687	Did not sustain
.03	1.017	0.0225	-	-	-	70	746	Did not sustain
.02	1.022	0.0320	3.02	0.338	900	71	1,332	Oxalic acid cooling test
.02	1.040	0.0225	-	-	-	68	774	Did not sustain
.02	0.836	0.0320	-	-	-	70	796	Did not sustain
.02	0.966	0.0225	-	-	-	69	919	Did not sustain
.02	0.821	0.0320	-	-	-	70	737	Did not sustain
.02	0.929	0.0320	-	-	-	68	932	$NaClO_4$ igniter used
.03	0.909	0.0320	9.52	0.095	270	69	692	Mixed oxidizer test
.03	1.027	0.0320	7.64	0.134	390	70	828	Mixed oxidizer test
.02	1.336	0.0225	-	-	-	70	728	Blew burst disk on ignition
.02	1.252	0.0320	9.37	0.134	370	69	751	Difficult to fabricate
.02	0.934	0.0320	0.85	1.10	250	68	1,059	Burst disk blew on ignition
.03	0.949	0.0320	2.42	0.392	1,060	68	1,073	Mixed oxidizers
.02	1.076	0.0320	16.15	0.067	205	70	650	Mixed oxidizers
.02	1.100	0.0320	10.76	0.102	290	65	833	Mixed oxidizers
.03	1.132	0.0320	-	-	-	69	760	Did not sustain
.03	1.188	0.0320	3.81	0.312	880	69	1,190	Mixed oxidizer
.02	1.268	0.0320	10.42	0.122	330	69	678	Baseline grind No. 1
.02	1.248	0.0320	7.98	0.156	430	70	692	SiO_2 processing aid
.03	1.150	0.0320	4.66	0.247	750	70	951	TFE processing aid
.03	1.254	0.0320	6.20	0.202	550	70	960	TFE processing aid
.02	0.965	0.0320	3.32	0.291	780	69	905	Mixed oxidizers
.02	1.031	0.0320	4.02	0.256	770	70	865	Mixed oxidizers
.03	0.861	0.0320	3.32	0.259	550	70	919	Baseline grind No. 2
.03	1.049	0.0320	5.75	0.182	530	70	783	Mixed oxidizers
.03	1.026	0.0320	3.29	0.312	850	69	978	SiO_2 processing aid
.03	1.159	0.0320	4.00	0.290	850	70	951	MoS_2 processing aid
.03	1.117	0.0320	3.44	0.325	935	69	1,023	MoS_2 processing aid
.03	1.027	0.0320	6.21	0.165	470	70	797	Mixed oxidizers

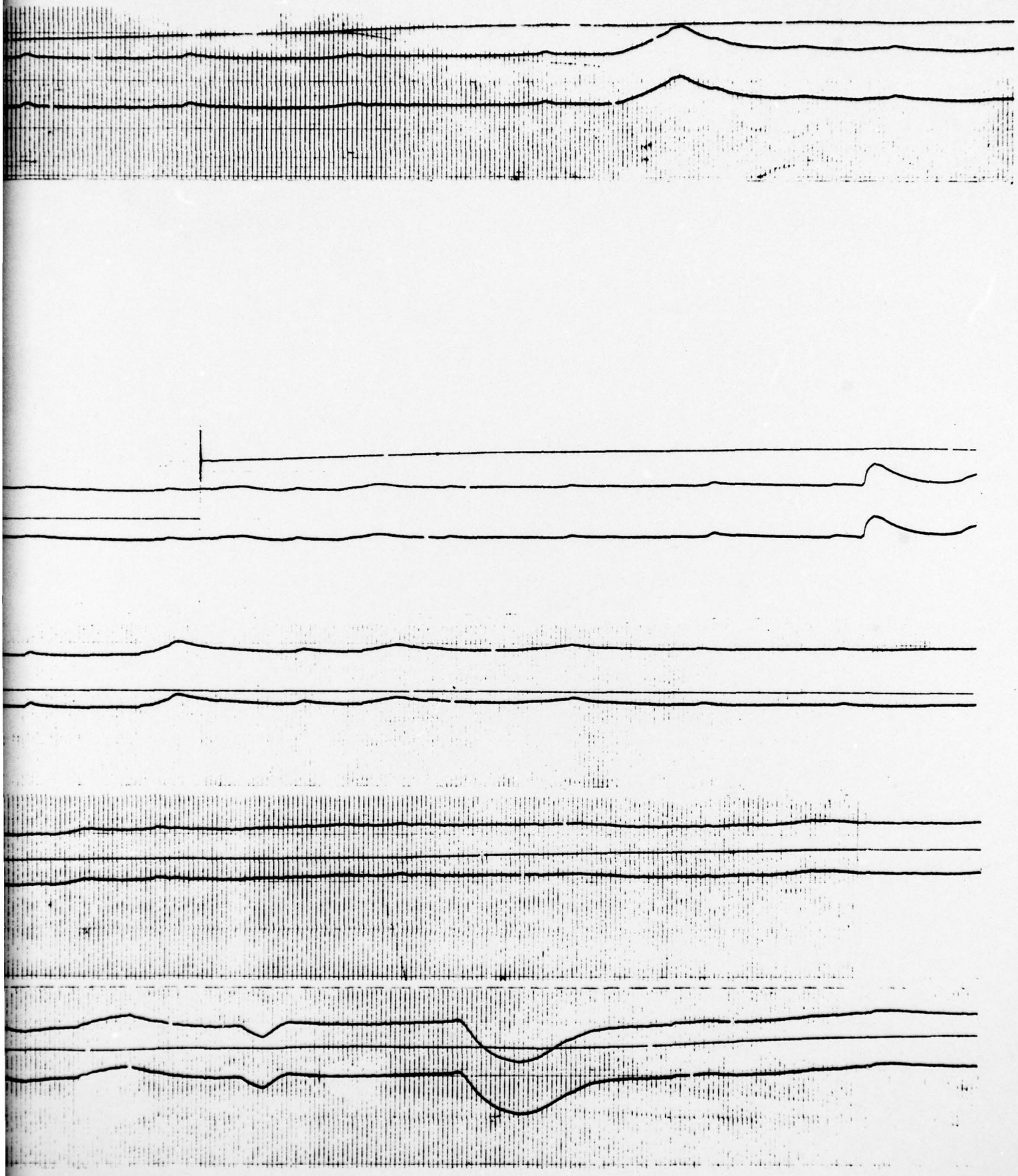
Number	Formulation, wt.-%	Grain Weight, g	Gas Weight, g	Yield, %	Ignition delay, sec	Grain length, in.	Throat Length, in.	Bu ti s
204	60 NaN_3/20 Fe_2O_3/ 20 MnO	63.93	25.40	39.7	0.03	1.034	0.0260	6
205	60 NaN_3/20 Fe_2O_3/ 20 MnO	63.83	24.95	39.1	0.03	1.056	0.0225	5
206	60 NaN_3/20 Fe_2O_3/ 20 MnO	58.96	21.77	36.9	0.03	0.962	0.0180	5
207	70 NaN_3/30 TiO_2	64.59	29.03	44.9	0.02	1.124	0.0320	5
209	60 NaN_3/20 Fe_2O_3/ 20 MnO	42.20	17.69	41.9	0.03	0.665	0.0180	4
210	60 NaN_3/20 Fe_2O_3/ 20 MnO	41.37	17.24	41.7	0.02	0.649	0.0180	4
211	60 NaN_3/20 Fe_2O_3/ 20 MnO	152.95	59.6	39.0	0.02	2.222	0.0180	16
212	63.1 NaN_3/21.9 Fe_2O_3/ 15.0 MnO	155.06	63.5	40.9	0.02	2.399	0.0225	14
213	63.8 NaN_3/26.2 Fe_2O_3/ 10.0 MnO	152.17	62.8	41.3	0.02	2.373	0.0250	12
214	63.8 NaN_3/26.2 Fe_2O_3/ 10.0 MnO	384.9	158.9	41.3	0.02	5.973	0.0280	31
215	63.8 NaN_3/26.2 Fe_2O_3/ 10.0 MnO	165.26	65.5	39.6	0.03	2.379	0.0250	20
216	63.8 NaN_3/26.2 Fe_2O_3/ 10.0 MnO	150.49	62.6	41.6	0.03	2.381	0.0200	15
217	63.8 NaN_3/26.2 Fe_2O_3/ 10.0 MnO	155.85	64.4	41.3	0.02	2.467	0.0250	7
218	63.8 NaN_3/26.2 Fe_2O_3/ 10.0 MnO	151.33	62.9	41.6	0.02	2.399	0.0292	7
219	70 NaN_3/30 TiO_2	139.05	60.2	43.3	0.03	2.468	0.0280	10
220	70 NaN_3/30 TiO_2	139.90	60.4	43.2	0.03	2.435	0.0292	9
221	63.8 NaN_3/26.2 Fe_2O_3/ 10.0 MnO	152.20	63.0	41.4	0.02	2.395	0.0280	11
222	63.8 NaN_3/26.2 Fe_2O_3/ 10.0 MnO	152.72	63.5	41.6	0.03	2.403	0.0320	12
223	63.8 NaN_3/26.2 Fe_2O_3/ 10.0 MnO	533.8	218.5	40.9	0.05	8.497	0.0310	46
224	63.8 NaN_3/26.2 Fe_2O_3/ 10.0 MnO	534.3	63.5	-	0.08	8.454	0.026	-
225	63.8 NaN_3/26.2 Fe_2O_3/ 10.0 MnO	544.7	224.0	41.1	0.03	8.555	0.037	36
226	63.8 NaN_3/26.2 Fe_2O_3/ 10.0 MnO	551.1	225.8	41.0	0.03	8.557	0.035	37
227	63.8 NaN_3/26.2 Fe_2O_3/ 10.0 MnO	540.6	268.4	-	0.11	8.467	0.023	59
228	63.8 NaN_3/26.2 Fe_2O_3/ 10.0 MnO	526.8	262.6	-	0.12	8.477	0.023	59

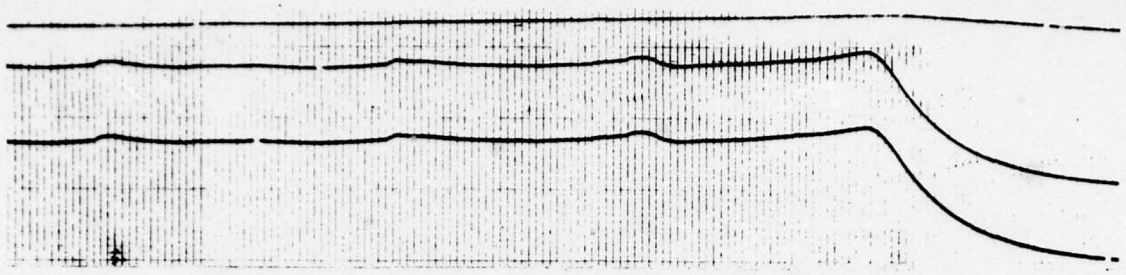
Grain length, in.	Throat Length, in.	Burn-time, sec	Burning Rate, in./sec	Pres-sure, psia	Tempera-ture, °F Grain	Gas	Comments
1.034	0.0260	6.20	0.167	670	68	797	Mixed oxidizers
1.056	0.0225	5.93	0.178	880	69	792	Mixed oxidizers
0.962	0.0180	5.50	0.175	1,040	69	787	Mixed oxidizers
1.124	0.0320	5.83	0.193	620	70	787	TFE lined case
0.665	0.0180	4.14	0.161	900	68	756	Mixed oxidizers
0.649	0.0180	4.09	0.159	910	69	828	Mixed oxidizers
2.222	0.0180	16.83	0.132	1,370	70	425	Flight grain, short
2.399	0.0225	14.93	0.161	1,090	69	473	Flight grain, short
2.373	0.0250	12.98	0.183	1,110	70	511	Flight grain, short
5.973	0.0280	31.25	0.191	1,140	70	692	Flight grain, long, baseline
2.379	0.0250	20.92	0.114	655	-40	411	Thermal condition test
2.381	0.0200	15.74	0.164	1,250	-40	329	Thermal condition test
2.467	0.0250	7.90	0.312	2,020	165	599	Thermal condition test
2.399	0.0292	7.99	0.300	1,490	165	567	Thermal condition test
2.468	0.0280	10.26	0.241	1,045	70	746	Filter test
2.435	0.0292	9.04	0.269	1,200	68	650	Filter test
2.395	0.0280	11.35	0.211	1,120	70	544	Filter test
2.403	0.0320	12.26	0.196	820	69	511	Filter test
8.497	0.0310	46.83	0.181	820	68	737	Conformance test
8.454	0.026	-	-	-	68	-	Conformance test, assembled incorrectly
8.555	0.037	36.68	0.233	795	165	742	Conformance test
8.557	0.035	37.24	0.230	900	165	-	Conformance test
8.467	0.023	59.90	0.141	1,060	-40	598	Conformance test
8.477	0.023	59.26	0.143	1,015	-40	608	Conformance test

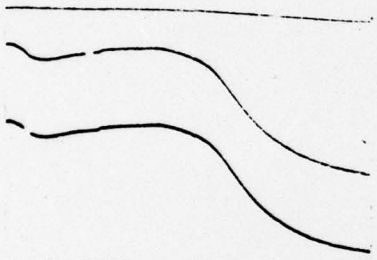
APPENDIX C

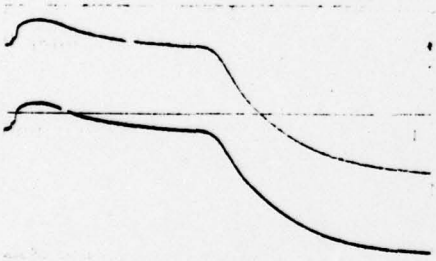
OSCILLOGRAPH TRACES OF CONFORMANCE TESTS

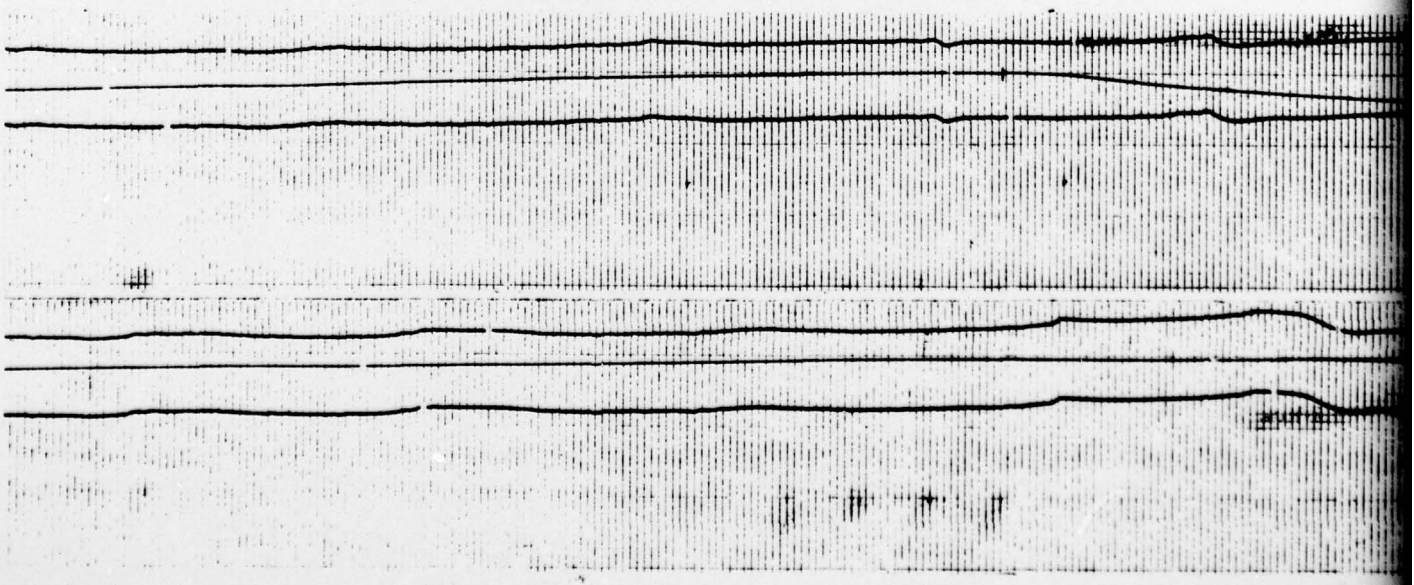

Test No. 223
Test No. 224
Test No. 225
Test No. 226
Test No. 227
Test No. 228

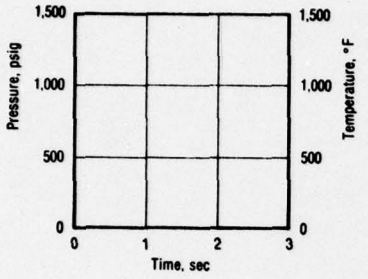











1,500
1,000
500
0
Pressure, psig
1,500
1,000
500
0
Temperature, °F
0
1
2
3
Time, sec